research QUARTERLY > Summer 2003

[Archives]

The Los Alamos Research Quarterly is published to communicate the Laboratory's achievements and how they benefit our neighbors, our nation, and the world.

The Research Quarterly highlights our ongoing work to enhance global security by ensuring the safety and reliability of the U.S. nuclear weapons stockpile, developing technical solutions to reduce the threat of weapons of mass destruction, and solving problems related to energy, environment, infrastructure, health, and national security.

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Staff

Scientific Editor
James L. Smith

Executive Editor
Judyth Prono

Art Director
Chris Brigman

Illustrator
Vicente Garcia

Writers
Jim Danneskiold
Brian Fishbine
Vin LoPresti
Marjorie Mascheroni
Eileen Patterson
James E. Rickman

Proofreader
Faith Harp

Printing Coordinator
Lupe Archuleta

Web Design
Michelle Gilliam

Research Quarterly, larq@lanl.gov

Dateline Los Alamos

Dean Martinez, a machinist in the Weapons Component Technology Group (NMT-5), adjusts a precision lathe before machining plutonium in the production area of the Lab's Plutonium Facility.

Lab Produces Qual-1 Pit

At a news conference held April 22, Director G. Peter Nanos announced that the Lab had achieved a major milestone: production of a nuclear weapon pit that meets specifications for use in the U.S. stockpile. Called Qual-1 because it was built with fully qualified processes, the pit culminates a six-year effort at the Lab's Plutonium Facility to restore the nation's ability to make nuclear weapons, a capability lost when the Rocky Flats Plant shut down in June 1989.

"Six decades ago, Los Alamos produced the first pit," Nanos said. "And today, on our 60th anniversary, we delivered to the Department of Energy a pit made with fully certified processes and made to all the specifications required for the nuclear stockpile." A pit is the fissile core of a nuclear weapon.

Linton Brooks, administrator of the National Nuclear Security Administration, noted that the achievement means that NNSA has met a key assignment set out by President Bush in his Nuclear Posture Review. "Since 1989 until today, we were the only nuclear power in the world that couldn't make a pit," Brooks said. "We now have the capacity that if something goes wrong with the stockpile, we can fix it." The Qual-1 pit is for the W88 warhead, which is carried on the Trident II D5 submarine-launched ballistic missile, a cornerstone of the U.S. nuclear deterrent.

The Department of Energy identified the Laboratory as the site for recapturing the nation's capability to manufacture pits in 1996, in part because we have the nation's only full-capability plutonium facility and have made pits since the 1940s. New pits are needed to replace those removed from the stockpile during periodic destructive surveillance and as reserves should surveillance studies identify pit problems that affect weapon safety, reliability, or performance.

To regain the pit manufacturing capability, the Lab modified the Plutonium Facility, acquired new equipment, and developed new fabrication technologies, materials, and processes. Forty-two processes are required to make a pit, all of which went through step-by-step design, engineering, and production reviews to confirm that they would result in pits that meet stockpile specifications. The processes also had to be qualified through extensive testing to demonstrate rigorous process control.

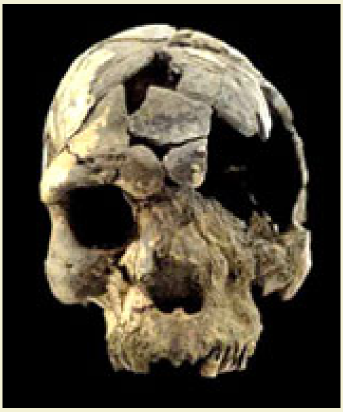
"All of these manufacturing processes meet today's health, safety, and environmental regulations, so some materials and processes differ from those used at Rocky Flats," Nanos said. For example, pits are now cleaned with environmentally responsible cleaners; the solvents used at Rocky Flats have been banned. While Rocky Flats used a wrought process to shape pits, the parts are now cast. Rocky Flats also used machine oil in all the manufacturing steps; pits are now dry-machined, with lubricant added only for the final pass.

To date, twenty pits have been produced as part of the Laboratory's pit manufacturing project. The first pit was completed in February 1998. In August 2002, the Lab made the first pit that used all forty-two processes required to make a certifiable pit. Qual-1 is the first pit manufactured that meets all quality requirements and could be placed in the stockpile if needed.

The Lab's next challenge is to complete the certification process for the newly manufactured pit by 2007. We will manufacture six pits a year from now until then to ensure that this milestone is met and to establish the capability to begin producing ten stockpile pits a year by 2007.—Jim Danneskiold

New Human Subspecies Announced

An international team of scientists, including Los Alamos geologist Giday WoldeGabriel, has announced the discovery of a new subspecies of modern humans, named Homo sapiens idaltu. Featured as the cover story in the June 12 issue of Nature, the discovery lends further credence to the hypothesis that modern humans originated in Africa.



Fossil of H. sapiens idaltu, housed in the National Museum of Ethiopia, Addis Ababa. Photo © 2001 David L. Brill/Brill Atlanta

In 1997, the team—known as the Middle Awash Research Group—discovered a fossilized skull and skull fragments of two adults and a child who lived in what is now the Afar region of northeastern Ethiopia, near the village of Herto. Argon-isotopic dating has put the fossils' age at 160,000 years old. Their age makes them the world's oldest fossils of near-modern humans, a fact alluded to by the reference to idaltu, which means elder in the Afar language. It took the team more than five years to successfully reconstruct and stabilize the fossilized remains.

The new subspecies is anatomically similar to modern humans. Before the Herto discovery, the oldest near-modern humans ranged from 90,000 to 130,000 years old and were found in Africa and the Middle East. The fact that H. sapiens idaltu predates the older (Middle Eastern) remains by 30,000 years supports the idea that modern humans originated in Africa and spread throughout the world from there.

Most significant to the research team, however, is the fact that the new subspecies is also unmistakably non-Neanderthal. The Herto fossils thus indicate that modern humans had evolved in Africa long before European Neanderthals disappeared. According to F. Clark Howell, a project co-leader from the University of California at Berkeley, the Herto fossils demonstrate that there never was a Neanderthal stage in human evolution and that Neanderthals were merely a branch of the evolutionary tree that later went extinct.

Following geological clues from satellite images and aerial photography, WoldeGabriel, lead geologist for the project, recommended that the team investigate the Herto site. After the fossils were discovered, he was also instrumental in characterizing the environment in which H. sapiens idaltu lived and resolving the fossils' age. Although much of Europe was under glacial ice at the time, the Herto subspecies lived near the shore of a large freshwater lake, a remnant of which exists today about a half mile west of its ancient shoreline, where the fossils were discovered.

Over the past decade, the Middle Awash Research Group has discovered a wealth of fossils in the Afar region. The team's finds include fossils of six early hominids ranging from one to six million years old in addition to the Herto fossils, its youngest find to date. —James E. Rickman

Mesa View

Carolyn Mangeng,
Acting Deputy Director

Responding to Changing R&D Challenges

As the Laboratory celebrates sixty years of national service, we have revisited many of the achievements that underpin our reputation as a premier scientific laboratory. The breadth of these achievements is remarkable, ranging from developing and maintaining the nation's nuclear stockpile to fostering major advances in scientific supercomputing and pioneering work on sequencing the human genome. Looking to the future, however, we see that the opportunities for new discoveries and technologies are no less remarkable. As a laboratory devoted to missions supporting national security, we could hardly face a more exciting landscape of challenges.

In our prime mission area—supporting the nation's nuclear weapons stockpile—forces of change are at work. There is a greater urgency to ground our certification responsibilities on a strong science base. There is also a growing recognition that the legacy stockpile may no longer achieve national defense goals. Although cautious not to incite proliferation, the national security community strongly supports a technologically responsive nuclear capability. This fiscal and political support for nuclear weapons is stronger than it has been for a decade.

Similarly, in areas of nonproliferation and counterproliferation—traditional strengths of Los Alamos—national demands for new technology continue to grow. There are emerging needs to provide greater security against terrorist threats to our homeland. The innovative neutron detector described in this issue is one means of improving our country's security against nuclear threats.

A very important new development is the call for defense transformation, championed by the secretary of defense, which would create more-flexible and responsive military forces, streamline the forces' capabilities for joint operations, and introduce state-of-the-art information technology into their operations. As discussed in this issue, Los Alamos is being challenged to provide advanced surveillance, sensor, and data mining and fusion technologies, as well as new concepts in conventional munitions, to help facilitate this transformation.

Other national challenges are also being addressed at the Laboratory. Health security challenges continue to draw on our bioscience capabilities, such as those in detecting, identifying, and tracing biothreats like anthrax. The need to enhance the nation's energy security is stimulating R&D work on advanced nuclear energy technologies and proliferation-resistant nuclear fuel cycles, as well as on fuel cells and the technologies needed for a hydrogen economy.

At the end of April, Dr. Robert Dynes, recently selected to be the next president of the University of California, spoke to a national security workshop at Los Alamos about the role of science and technology in national security. He said, "Leading science is stimulated by a problem-rich environment." That environment is indeed upon us. It is our unique challenge, Dynes noted, to provide the intellectual leadership that will underwrite the security of the nation.

Versatile EXPLOSIVES

“Playing” with Fire

by Vin LoPresti

Fireworks propelled by high-nitrogen energetic materials display vibrant colors and patterns in a virtually smoke-free environment. These vivid pyrotechnics eliminate sulfurous fumes and minimize the use of toxic colorants.

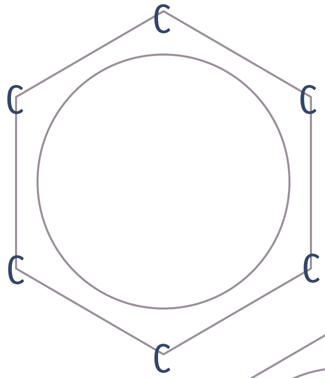
John Flower

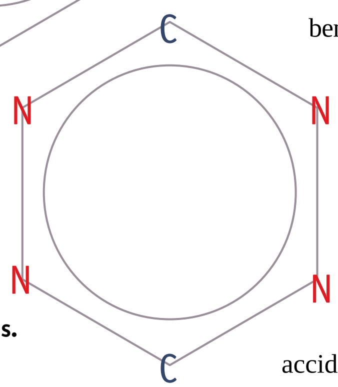
Smokeless, odorless, and delayed response—these are not characteristics typically associated with explosives. But Laboratory researchers have been focusing on a group of compounds—high-nitrogen energetic materials—that are challenging stereotypical notions of how explosives behave. In addition to their use in weaponry, these compounds have applications in fire suppression, entertainment, and automobile safety.

Traditionally, explosives have been substances rich in carbon—for example, the charcoal in gunpowder. Combustion of a carbon-rich explosive in air results in the formation of carbon dioxide and carbon monoxide, together with water vapor and soot (unburned carbon particulates). Energy is rapidly liberated, accompanied by high temperatures (see the combustion primer on page 7). When combustion occurs within a gun barrel, the hot gases expand and propel a bullet or other projectile toward its target.

High-nitrogen energetic materials contain more nitrogen than carbon by weight, and their combustion products therefore differ from those that result from carbon-rich compounds. Nitrogen gas (N_2, which makes up 78 percent of Earth's atmosphere) is a main combustion product. Additionally, the high nitrogen content of these materials often leads to high densities; that is, individual molecules of the material pack closely together, so that a small quantity of the compound contains more combustible material than would a less dense compound. This high density is desirable in an explosive, in that large amounts of energy can be liberated from a relatively small amount of material.

The high-nitrogen compounds occupying the attention of a Los Alamos team in DX-2 (Materials Dynamics Group) are derivatives of the 1,2,4,5 tetrazine ring, a benzenelike, or aromatic, chemical structure in which





Comparison of the benzene (above) and tetrazine (right) rings emphasizes the predominately nitrogen composition of tetrazine compounds.

four of the six carbon atoms in the benzene ring are replaced by nitrogen. Many of the tetrazine-derived compounds studied to date share the quality of “insensitivity”; that is, they will detonate only upon reaching a target but not when subjected to high temperature, friction, or accidental impact.

John Flower

(Top) Combustion of a conventional explosive pellet is accompanied by flame, smoke, and residue. (Bottom) By comparison, combustion of a DHT pellet is nearly smokeless and flameless. The DHT pellet is encased by epoxy resin (arrow) to control combustion conditions; this was unnecessary for the conventional explosive because of its relatively slow combustion rate.

Empirical Chemistry

Because the tetrazine ring does not exist in nature, its similarity to benzene can be misleading. The synthesis of tetrazine compounds does not proceed directly from benzene and can require a long series of reaction steps. As many organic chemists would attest, chemical syntheses are part understanding, part experience, and part trial and error, sometimes with a healthy dollop of luck stirred in.

tetrazine). Because it is both a high-nitrogen and a high-hydrogen compound, it tends to burn hotter in air, forming both nitrogen gas and water. These characteristics make it a candidate for so-called thermobaric bombs. First used in Afghanistan during the March 2002 attacks on Al Qaeda caves, these bombs use a primary explosion to propel a solid-fuel explosive into a tunnel, bunker, or cave. The secondary explosive then detonates via a delayed fuse to generate both high heat (*therme*) and high pressure (*baros*) within the enclosed space. Finely divided fragments of aluminum metal are often included in the solid explosive, because in the high-energy environment of the explosion, aluminum oxidizes in air. Forming aluminum oxide, this reaction both consumes significant oxygen and generates additional heat (it is highly exothermic).

Chemical syntheses are part understanding, part experience, and part trial and error.

By modifying the molecular groups bonded to tetrazine rings, the DX-2 team of Mike Hiskey, Darren Naud, David Chavez, and My Hang Huynh has synthesized a host of compounds that differ in the rate and the temperature at which they burn. “You never know exactly quite what you’ll get. You set out to make one thing and then find other applications,” comments Hiskey, alluding to the fact that it is often difficult to predict a compound’s properties before synthesizing it.

One compound the team has synthesized is DHT (dihydrazino-

The army and navy are testing DHT-aluminum as a candidate explosive because, in addition to its high density, its detonation also generates significant volumes of nitrogen gas. When the gas replaces the oxygen consumed by the burning aluminum, a nitrogen-rich atmosphere is created that leads to nitrogen narcosis in anyone exposed to it. This physiological phenomenon was originally described in deep-sea divers. As the total gas pressure increases with increasing dive depth, the partial pressure of nitrogen increases, and more nitrogen becomes dissolved in the blood—and therefore in the brain. Dubbed "rapture of the deep," this misnomer alludes to the fact that nitrogen's intoxicant and soporific effects are equivalent to those of one martini on an empty stomach for each 50 feet beyond a 100-foot dive. Since nitrogen impairs the conduction of nerve impulses, at very high brain concentrations, nitrogen narcosis is fatal.

Cleaner Pyrotechnics

Ironically, the same compound that can be weaponized can also entertain. The hot flame and carbon-free combustion of DHT have made it ideal for a new generation of reduced-toxicity fireworks. Traditional carbon-based fireworks generate large quantities of sooty, sulfurous smoke that interferes with viewing and can also cause respiratory discomfort or asthmatic reactions in audiences. Remaining unseen are constituents that are even more toxic: carbon monoxide and the heavy metals (for example, barium) used as colorants.

The odorless, colorless nitrogen gas released in the combustion of DHT enables brighter, more deeply saturated display colors with only one-tenth the conventional amount of metal-ion colorants. DHT's hot flame also allows the use of safer substitutes for traditional colorants, for example, boric acid instead of barium. Moreover, the absence of carbon monoxide, soot, and sulfurous fumes makes DHT-powered fireworks much safer for indoor use.

Hiskey's interest in fireworks and high-energy chemistry dates back to his teens, and that curiosity provided him

Cannons to Carbohydrates: A Combustion Primer

Explosives are compounds that rapidly liberate energy when chemically rearranged through combustion. Energy (typically in the form of a flame or an electrical discharge) ignites the explosive and breaks weaker chemical bonds in the explosive molecule, rearranging its atoms to form new, stronger chemical bonds. This new bond formation liberates energy that makes the reaction self-sustaining. Overall, forming new bonds liberates much more energy than what is needed to break the original bonds, resulting in a net release of energy, including heat—a so-called exothermic reaction (*exo* meaning out; *therme* meaning heat).

For example, in the combustion of gasoline (C_7H_{16}) in air, carbon-carbon and carbon-hydrogen bonds are broken, and carbon-oxygen and hydrogen-oxygen bonds are formed, producing carbon dioxide, carbon monoxide, and water vapor. Combustion is rapid, and energy is liberated as an explosion within a car engine's cylinders, with the heated gases expanding and exerting a force on the pistons.

When your body cells burn food for energy, fundamentally the same exothermic chemistry occurs with the bonded atoms in food molecules such as fat, which is mostly carbon and hydrogen. The oxygen that we breathe and that is distributed by the bloodstream to all our body cells ultimately supplies the oxygen atoms to create carbon dioxide and water. But the bonds are broken and formed gradually, in many carefully controlled steps, so that energy is liberated slowly rather than explosively. Nonetheless, we correctly speak of "burning fat," a nonexplosive form of combustion known as cellular respiration. That this is an exothermic process is demonstrated by body heat. The faster we "run" our metabolism (such as when we burn more fats or carbohydrates during exercise), the warmer our bodies get. Sweating dissipates the heat and regulates body temperature.

Powered by sunlight, trees perform this metabolic process in reverse (thermodynamically, but not in terms of the details) in photosynthesis. The resulting carbohydrate, cellulose, is burned as wood to form the charcoal used to make gunpowder—first documented in the Middle East in 1200. It has taken 800 years for chemists to discover viable gunpowder alternatives in the form of high-nitrogen energetic compounds.

U.S. Navy

U.S. Navy

Naval gun propellants, past and present. Sixteen-inch guns on the battleship New Jersey spew the smoke and flame characteristic of carbon-rich propellants (Persian Gulf, 1989). (Inset) Today's naval guns, like this five-inch gun on a destroyer, may undergo less wear through the addition of high-nitrogen energetic materials to propellants.

with both a practice-based learning environment and a career path. Teaming with Naud and Chavez, Hiskey developed a cost-effective synthesis of DHT, which led to "smokeless" fireworks. Their invention won an R&D 100 Award in 1998 and has drawn the interest of at least one major theme park.

Better Big-Gun Propellants

As most gun owners know, the high gas temperatures and sooty residues produced by the combustion of gunpowder mandate frequent cleaning of gun barrels. Less appreciated is the wear and tear on a gun barrel produced by carbon-based propellants. This wear is of particular concern for military guns, whose powerful blast charges propel projectiles to targets miles away. Another tetrazine relative, known as GUZT (guanidinium azotetrazolate), may help reduce such wear when added to gun propellants.

In gun barrels, the propellant is burned behind a projectile, and—in accord with gas laws—the expanding gases from that combustion exert pressure on the projectile, accelerating it toward a target. During this process, two major sources of wear contribute to reducing gun barrel life. First, the combustion's very high temperature deforms metal alloys in the barrel. Second, carbon-based propellants generate significant carbon monoxide, which at elevated temperatures, reacts to form metal carbides that embrittle the barrel's interior, resulting in increased wear.

A high-nitrogen propellant additive like GUZT addresses both issues. Its lower-temperature combustion moderates temperature deformation, while its generation of nitrogen gas helps mitigate reactivity. In sufficient concentration, nitrogen gas can inhibit the carbon monoxide–gun barrel reaction, thereby reducing the extent of metal carbide formation.

For barrels as large and as expensive as those on naval warships, this reduced wear could represent significant cost savings. Barrels are currently replaced after every eight thousand rounds fired, and the navy expects the replacement frequency to rise as more-energetic propellants come into use. But the cost of the barrel is overshadowed by two other factors. Since barrels cannot be replaced at sea, there is the expense of bringing a ship back to port for the work. More important from a strategic standpoint is the impact of this return to port on fleet readiness.

Fighting Fire with Fire

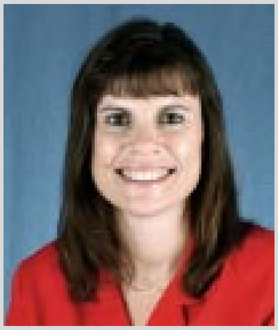
A compound known as BTATz (bistetrazolylaminotetrazine) has shown considerable promise as a fire suppressant. The current suppressant of choice is Halon-1301 (bromotriflouromethane). Halon works by evaporating within a fire and displacing the oxygen that would sustain the blaze. It has several drawbacks, however. First, it destroys Earth's ozone layer (its production was thus halted in 1994). Second, as a gas, it is stored in pressurized bottles for application as a liquid. Particularly for use in an airplane, these bottles add undesirable weight.

For several years, the U.S. military has been evaluating solid and hybrid (solid/liquid, solid/gas) fire suppressants, and the properties of BTATz rank it among the more promising agents now undergoing evaluation. Almost 80 percent nitrogen by weight, BTATz burns very rapidly to form 0.7 liter of nitrogen gas per gram of solid combusted. Because of its low carbon content, it burns cleanly, without smoke, leaving a minimal residue. And like GUZT, it burns at a temperature hundreds of degrees lower than do carbon-rich compounds of similar molecular weight.

The large volume of inert nitrogen gas rapidly generated by BTATz is precisely what is needed to displace

Interagency Partnering

Dr. Christine Walsh
Advanced Gun Propellant Development Program Manager
Naval Surface Warfare Center, Indian Head Division
Indian Head, Maryland



U.S. Navy

Decreasing federal budgets have put a premium on teaming between governmental agencies to provide innovative, cost-effective solutions to the military's needs. For example, a memorandum of understanding between the Departments of Defense and Energy specifies that the Department of Energy will develop and transition technologies that are of interest to the Department of Defense.

Under this agreement, I am collaborating with a team led by Mike Hiskey at Los Alamos National Laboratory. His team is developing novel energetic ingredients that can be used as additives in explosives and propellant formulations. These ingredients help solve some of the technical issues associated with improving weapons technology, allowing the navy to provide military forces with better-performing weapons.

As the lead for gun propellant development for the Naval Surface Warfare Center at Indian Head, I am responsible for the development of novel gun propellants for the navy. These propellants are designed to provide better protection for sailors and soldiers by increasing ship-to-shore stand-off distances—allowing ships to stay out of harm's way—and by increasing fire support for land-based troops, such as the marines. This Los Alamos–U.S. Navy collaboration allows both organizations to leverage each other's technology and scientific expertise to provide mutually beneficial solutions to real-world needs. It exemplifies a partnership demonstrating that the whole is greater than the sum of its parts.

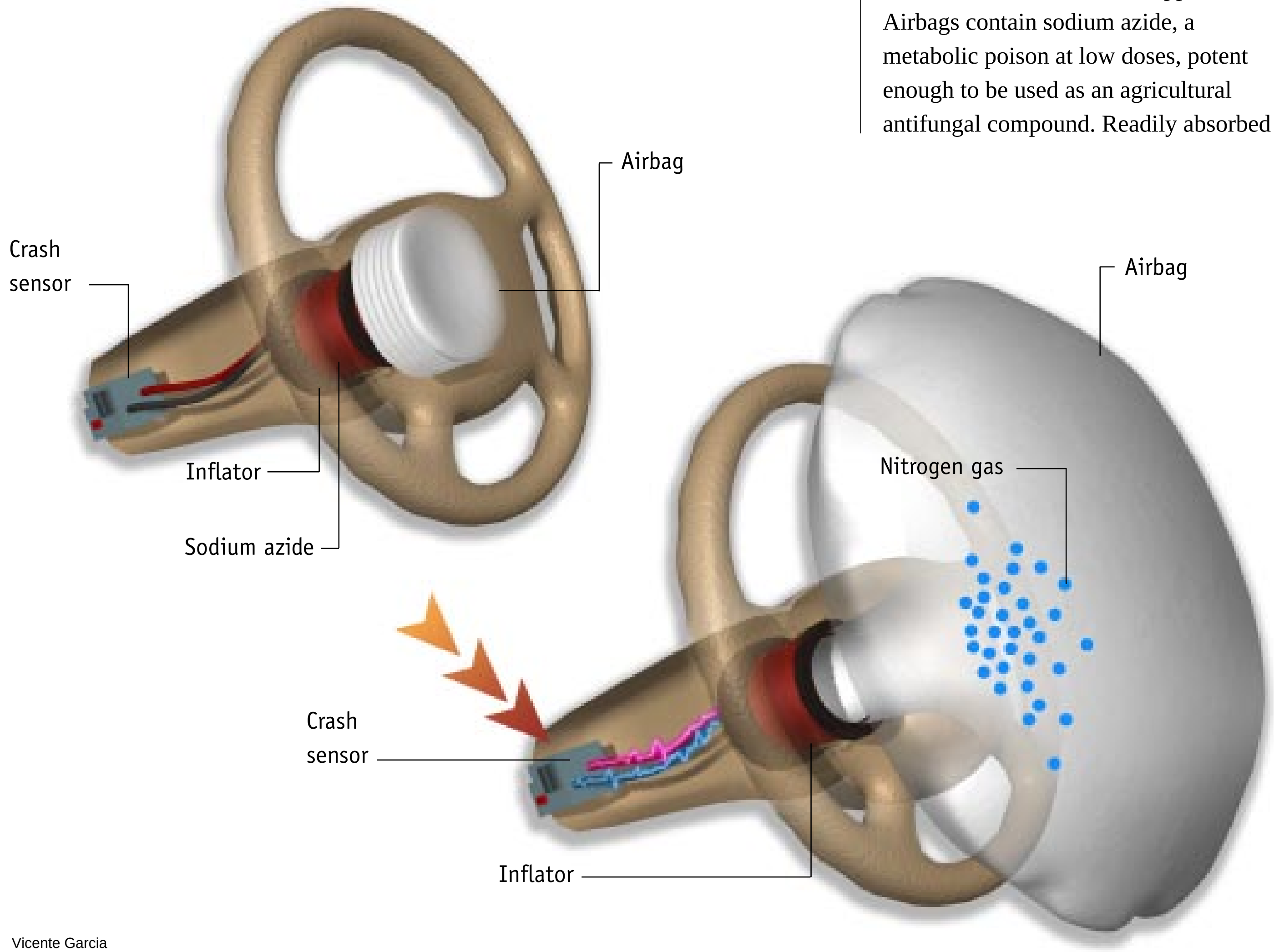
The basics of airbag inflation. (Top) An undeployed airbag is folded within a car's steering wheel, its sodium azide–containing inflator attached to the crash sensor in the steering column. (Bottom) Activated by a crash (arrows), the sensor triggers the inflator to produce an electric spark that ignites the sodium azide, which rapidly produces nitrogen gas that inflates the airbag.

oxygen from the vicinity of a fire. Nitrogen gas is composed of smaller, less-massive molecules than vaporized halon, and nitrogen's more rapid rate of expansion helps cool its surroundings (all gases absorb heat from their environments as they expand). BTATz thus addresses a problem encountered with other fire suppressants, namely, effluent gases that are too hot.

As a solid, BTATz can be formed into a paint that, when applied to a surface (such as the wheel well of a carrier-based aircraft), will remain chemically stable until it ignites. Requiring no heavy storage containers, it is also lighter than halon. BTATz now costs $75 per pound to manufacture, but the navy's Air Warfare Weapons Division at China Lake, California, is seeking to scale up its synthesis, thus further reducing its cost. The navy is also experimenting with combining BTATz with flame inhibitors. Since halon is also the civilian fire suppressant of choice, this research may ultimately produce a widely used, environmentally friendly fire suppressant.

Airbags

Gas-generating solids are used in automobile airbags, and BTATz is also a candidate for this civilian application. Airbags contain sodium azide, a metabolic poison at low doses, potent enough to be used as an agricultural antifungal compound. Readily absorbed



Vicente Garcia

through the skin and lungs, it can cause cardiovascular abnormalities, convulsions, and upon prolonged exposure, even death. Although airbags contain very small quantities of the chemical, eliminating it from automobiles is clearly desirable, particularly since it also accumulates in landfills where undeployed airbags are discarded.

In an automobile accident, a crash sensor activates a circuit that sends an electrical discharge into the sodium azide, causing it to ignite and decompose into sodium metal and nitrogen gas, which rapidly expands to inflate the airbag (see sidebar on airbag chemistry). Although currently more expensive than sodium azide, BTATz efficiently generates nitrogen gas, and it may well find an application in this area if its synthesis cost can be lowered.

Small-Scale Rocket Propellants

From GPS data to live transoceanic newscasts, satellite communications have become central to our way of life. Despite satellites' generally stable orbits, their orientations must occasionally be fine-tuned by tiny

NASA

Microthrusters on the Jason-1 satellite maintain a precision orbit for its mission: to accurately determine ocean height and monitor global ocean circulation.

Airbag Chemistry

Folded (undeployed) airbags—in the steering-wheel assembly and passenger-side dashboard of all new vehicles—contain sodium azide (NaN_3), a potent metabolic poison. Although the precise formulations used are guarded as trade secrets, a well-known one includes potassium nitrate (KNO_3) and silicon dioxide (SiO_2) as secondary reactants. In the gas generator, a mixture of sodium azide, potassium nitrate, and silicon dioxide is ignited by an electrical impulse. This liberates a volume of nitrogen gas (N_2), which rapidly fills the airbag:

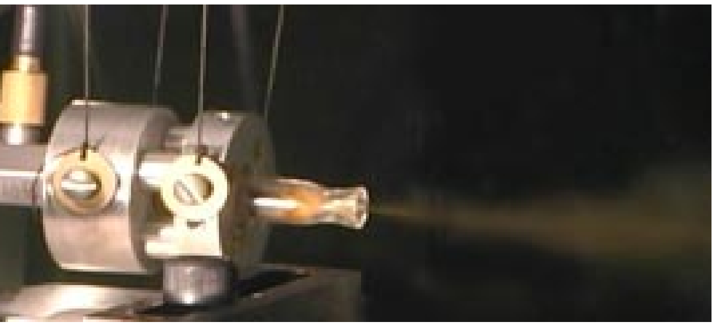
$$2NaN_3 \rightarrow 2Na + 3N_2 .$$

Sodium metal (Na), the other byproduct of this reaction, is an unstable substance that can undergo an explosive reaction with water at room temperature (a common demonstration in college chemistry classes). This sodium reacts with the potassium nitrate to generate additional nitrogen for the airbag in a second reaction:

$$10Na + 2KNO_3 \rightarrow K_2O + 5Na_2O + N_2 .$$

The other products of the reaction—potassium oxide (K_2O) and sodium oxide (Na_2O)— react with the third compound of the original airbag mixture, silicon dioxide (SiO_2), to form alkaline silicate, or glass, a stable (unreactive) substance that is harmlessly discarded in a deployed airbag.

The use of BTATz, which produces only water, carbon dioxide, and a large amount of cool, inert nitrogen gas upon ignition, would eliminate the need for the supplementary chemicals and secondary reactions, and more important, would eliminate the need to dispose of the toxic sodium azide from undeployed airbags.



John Flower

A satellite microthruster is shown next to a dime for size comparison (top) and in the process of combusting the solid propellant DAAT-N-Ox (bottom). With a diameter of about 1 millimeter, the thruster's nozzle would be rapidly clogged with deposits from combustion of a carbon-based fuel.

rocket motors (microthrusters). Inspection satellites, launched to inspect other orbiting equipment, also use these thrusters.

Yet another tetrazine derivative, dubbed DAAT-N-Ox, shows promise as a solid fuel for such rocket motors. Like BTATz, DAAT-N-Ox burns at a lower temperature than do conventional solid propellants. These lower temperatures allow the use of materials for rocket nozzles that would otherwise melt during combustion. Such nozzles are frequently only about a millimeter wide at their narrowest point, so they would also rapidly become clogged with the residues deposited by hotter-burning carbon-based fuels. However, DAAT-N-Ox burns very cleanly, thus avoiding nozzle clogging. It also burns much more rapidly than any carbon-rich energetic material, perfectly suiting it for the very short propulsive bursts needed to make minor changes in satellite orientation and orbits. With the fastest combustion rate of any solid rocket fuel, DAAT-N-Ox may well be the best solid propellant available.

DAAT-N-Ox may well be the best solid propellant available.

Variations on a Theme

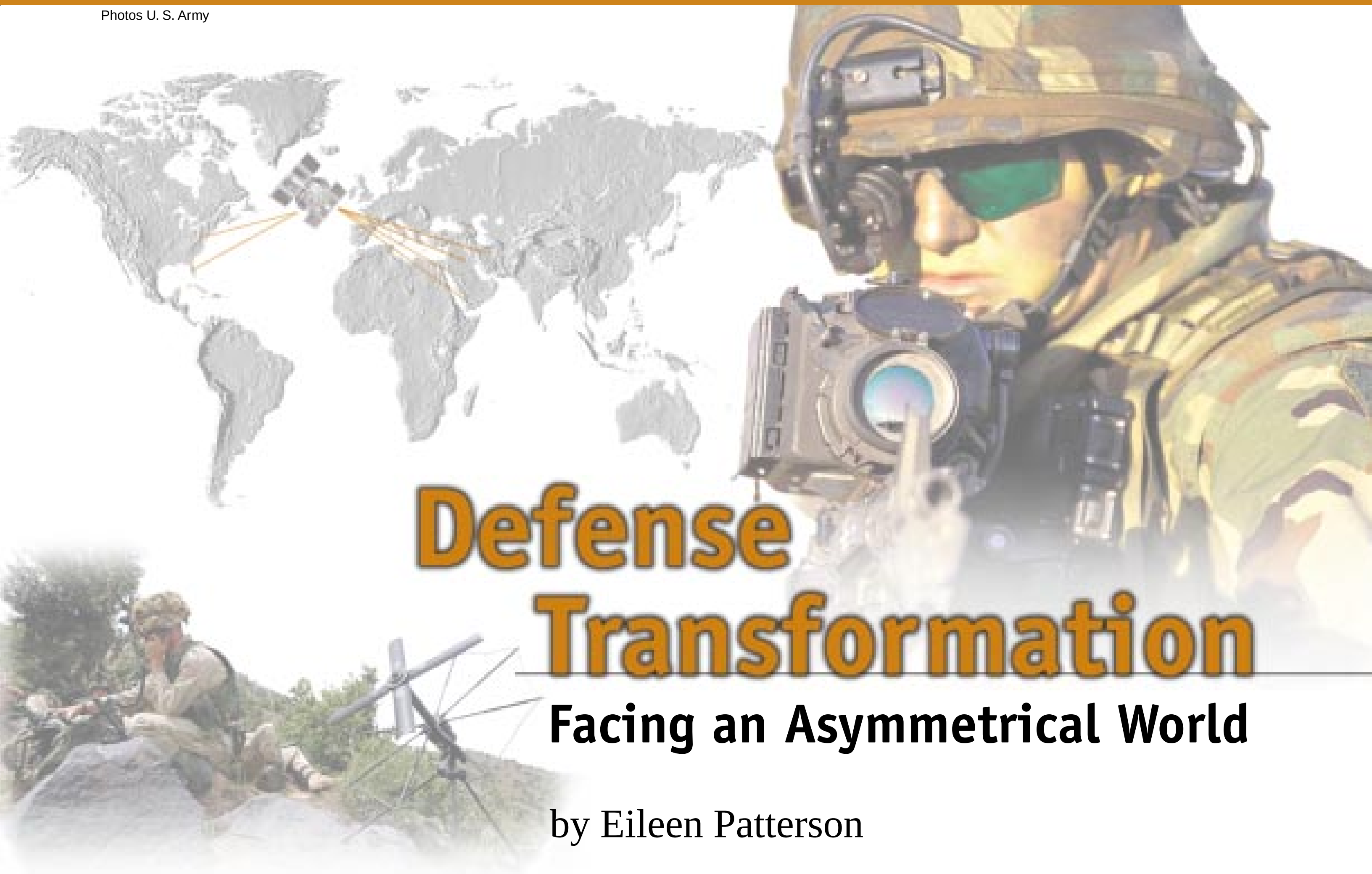
From microthrusters to naval gun propellants, from thermobaric bombs to smokeless fireworks, from fire suppression to airbag inflation, high-nitrogen compounds promise unique versatility as energetic materials. Their insensitivity, high density, and lower combustion temperatures are attractive characteristics for explosives and rocket motors. Their rapid generation of inert nitrogen in large volumes is ideal for both existing and future applications that require an environmentally friendly gas generator. Although not quite a case of "one compound fits all," these tetrazine derivatives represent variations on a theme, and it appears likely that current and future compounds will find useful niches in both military and civilian life. ■

The Researcher

John Flower

Michael Hiskey received a Ph.D. in explosives chemistry from New Mexico Institute of Mining and Technology in 1990. He then joined the Laboratory as a postdoctoral researcher and became a technical staff member at DX-2 in 1992. He holds patents in the areas of explosives, propellants, pyrotechnics, and gas generants.

Photos U. S. Army



Defense Transformation

Facing an Asymmetrical World

by Eileen Patterson

> *"The future holds many unknown dangers and . . . we fail to prepare for them at our own peril."*
> *—Donald Rumsfeld*

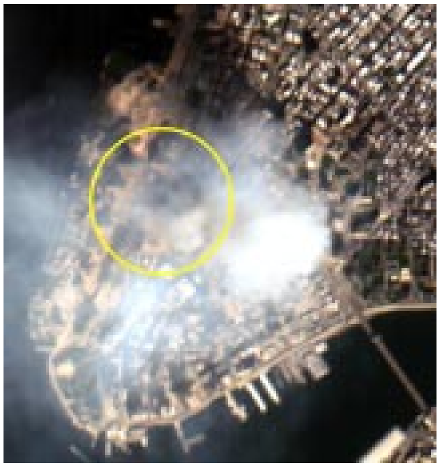
The attacks of September 11, 2001, reminded us that the end of the Cold War was not the dawn of a safer era. Although the Soviet Union's monolithic power is gone, other aggressive states and rogue groups have filled the void. In response, the Department of Defense is calling for a transformed defense policy—a constantly evolving entrepreneurial approach in which technical creativity keeps the United States' military forces ahead of the competition at every turn. It is an approach Defense Secretary Donald Rumsfeld sees as necessary because "the future holds many unknown dangers and . . . we fail to prepare for them at our own peril."

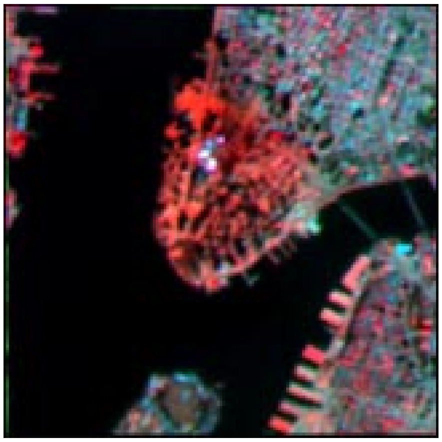
Farewell to Symmetry

Although the Cold War years were tense, it was a balanced tension—two deadlocked superpowers with comparable caches of mostly nuclear weapons. For all intents and purposes, those caches canceled each other out. Mutually Assured Destruction (MAD), the defense strategy of the time, was meant to ensure cancellation: aggression and the response it triggered would devastate both sides.

MAD worked because it pitted *like* force against *like* force and because it relied on a mutual desire for survival. It was based on symmetry, and symmetry kept the peace—mostly—for decades. What has existed since then, and what we saw exhibited on September 11, is known to the Defense Department as "asymmetry."

An asymmetrical world is a world of dissimilar forces: hostile countries or groups with inferior militaries facing the one remaining military superpower, the United States. Our nation's new enemies may possess or be in pursuit





The Multispectral Thermal Imager (MTI), a satellite-based sensor, collects data in fifteen spectral bands that provide information—for example, surface temperature and material composition—about sites on Earth. Following the events of September 11, 2001, MTI was used to help analyze the devastation in lower Manhattan. The data shown here are a color image (with a circle superimposed to indicate ground zero) and a temperature map of the area. The MTI is an R&D satellite designed to demonstrate and evaluate advanced space-based imaging technology. It was developed by the Department of Energy's Sandia and Los Alamos National Laboratories and Savannah River Technology Center.

of weapons of mass destruction, or they may be dedicated to terrorism, which does not require advanced technology to be devastating. In addition, they may have no compunction about sustaining losses when they attack. With no fear of death, an inferior force can inflict unacceptable losses on even a country that is militarily superior in the traditional sense. This new world is dangerous.

The Shift Is On

New dangers call for new thinking and a new defense posture. The Defense Department's plans for transformation focus on a lighter, more-flexible military, one that relies less on overwhelming numbers—of tanks, bombers, or missiles—and more on stealth, rapid response, and precision weaponry. Accurate, multidimensional intelligence and advanced information technology will provide the backbone. Data from diverse and globally dispersed sensor and human intelligence networks will be gathered and analyzed to give our nation's battlefield and homeland defenders a constant awareness of emerging threats.

This new "global situational awareness" will be crucial to defense in an asymmetrical world. In addition, computer networking, which has already revolutionized business communications, will interlink military units and their command posts, allowing for real-time, cooperative responses to incoming intelligence.

Defense transformation also links to a new triad of offensive and defensive capabilities. *Triad* was first used as a label for the nation's three-pronged strategic nuclear force: submarine-launched ballistic missiles, land-based intercontinental ballistic missiles, and long-range bombers. The new triad encompasses a wider range of capabilities: (1) nuclear and nonnuclear strike capabilities; (2) passive and active defenses, including missile defense; and (3) the defense-industrial infrastructure, which includes the labs and industries that develop, produce, and maintain the new-triad technologies.

There will be no one moment when the defense transformation is complete. Secretary Rumsfeld speaks of "a culture of continual transformation, so that our armed forces are always several steps ahead of any potential adversary." As the premier nuclear weapons laboratory, Los Alamos has been a major source of technology for a defense posture centered on nuclear weapons, and the Lab's continued nuclear and stockpile stewardship expertise will remain vital. But how does the Lab fit into the new defense transformation picture?

Transformational R&D at Los Alamos

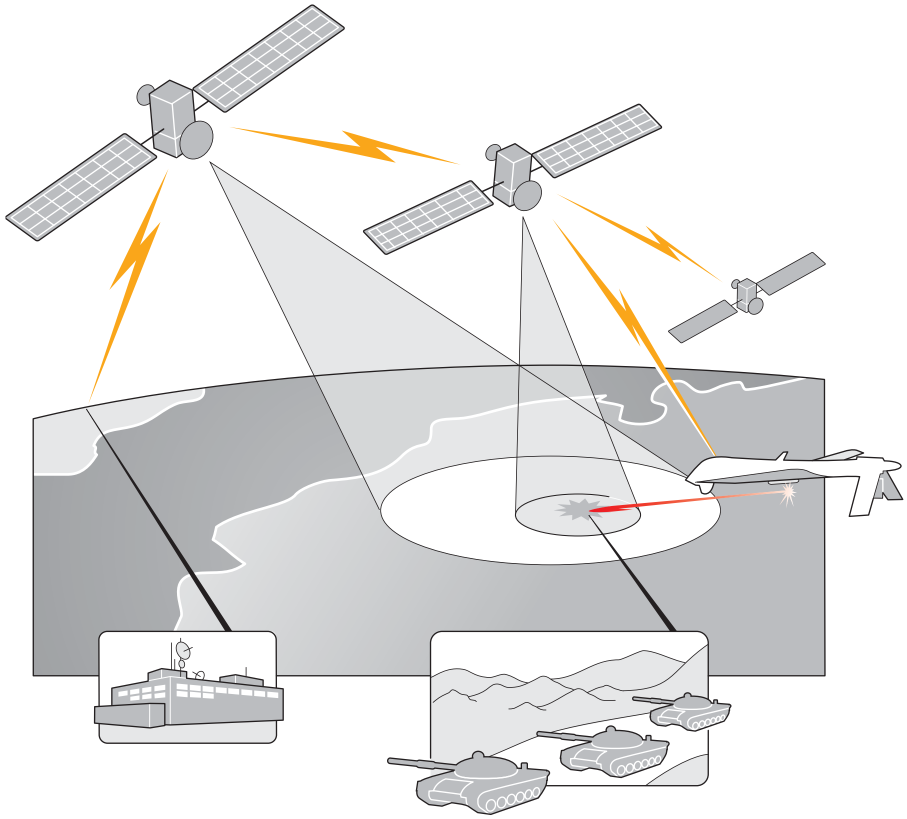
The task of answering that question rests with the Directorate for Threat Reduction. Paul Weber, the directorate's newly appointed deputy associate director for defense science and technology, is leading a push to define how Los Alamos can best contribute. He is already seeing an arsenal of Laboratory technologies, developed in fulfillment of the Lab's Department of Energy mission, that fit the defense transformation bill.

In the realm of advanced weaponry, Los Alamos is working toward the development of directed-energy weapons such as a megawatt free-electron laser that can be mounted on a ship to propagate a speed-of-light destructive beam against incoming targets. The Lab is also working on advanced energetic materials whose energy release rates can be tailored to specific targets and others whose insensitivity to impact allows them to reach deeply buried targets.

For homeland security, Los Alamos, along with Lawrence Livermore National Laboratory, has already developed and deployed BASIS, the Biological Aerosol Sentry and Information System. Used to detect airborne biological threats at the 2002 Winter Olympics in Salt Lake City, BASIS won a 2003 R&D 100 Award as one of the year's 100 most significant technological advances. It is currently being fielded nationwide as part of the country's BioWatch surveillance program for urban areas.

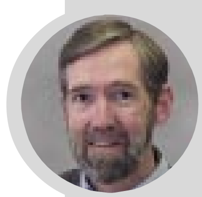
Los Alamos has developed and fielded both terrestrial and space-based sensors. In fact, Los Alamos sensors already fly on all global positioning system and Defense Support Program satellites. The Lab has also developed sophisticated imaging and visual-analysis systems such as GENIE (Genetic Imagery Exploitation) and the Multispectral Thermal Imager (see the figure on page 14). These join the Laboratory's advanced data-processing and analyzing capabilities and our secure-communication technologies (for example, quantum cryptography for secure data transmission). Such technologies make the Lab a valuable contributor to the quest for global situational awareness.

Our contributions to national defense are already well documented. Our continued technological preeminence will allow the Laboratory to fit very comfortably into the defense transformation future. ■



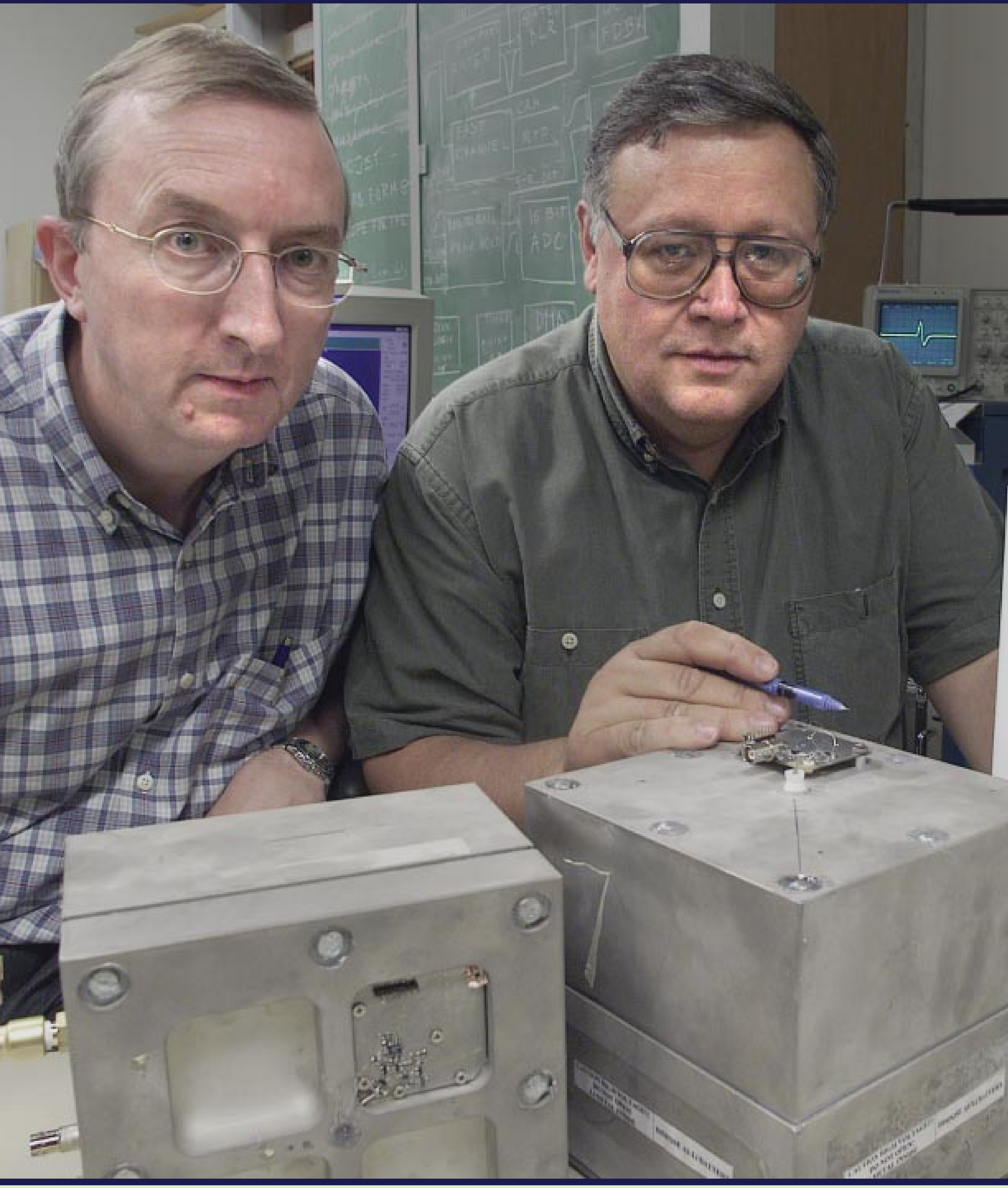
Vision of future response to global threats. A constellation of rapidly launched minisatellites in low-Earth orbit provides continual surveillance of an area of conflict. Each satellite provides wide-area sensing and detection, local imaging and precise target identification, onboard data processing, and communication with one another as well as with unmanned aerial vehicles and command headquarters in the United States. As pictured here, the first satellite forwards information on potential activity from its wide-area surveillance to a second satellite, which identifies tank movement in its narrower field of view and directs an unmanned aerial vehicle to fire on the tanks; the third satellite then assesses the resulting damage. The elapsed time from wide-area sensing to damage assessment is only ten minutes. Such rapid response will draw on the Lab's R&D work on sophisticated imaging and visual-analysis systems, advanced data-processing techniques, and secure communication technologies.

The Researcher



John Flower

Paul G. Weber leads the Laboratory's new initiative in defense transformation. His background is in plasma physics, space and atmospheric sciences, remote sensing, and other advanced measurement systems. Weber was the division leader of Earth and Environmental Sciences before being named to his new post in the Threat Reduction Directorate. He holds a Ph.D. in physics from Flinders University, South Australia.



John Flower

Kiril Ianakiev (right) points to an electronics package on a single-cell prototype of his modular neutron detector. The detector is made of high-density polyethylene, a tough, durable plastic. Metal cladding on the exterior surfaces of the two single-cell prototypes shields their electronics from the electrical noise produced by power lines and other external sources. Measurements made with the prototypes have confirmed calculations of their neutron detection efficiency done by Martyn Swinhoe (left). The plastic detector body on the right will be used to build an eight-cell detector—the first fieldable version of the modular detector.

A Modular Neutron Detector

by Brian Fishbine

Lab scientists have developed a rugged, inexpensive neutron detector—made largely of plastic—that could be mass-produced to provide more-widespread border screening for nuclear contraband.

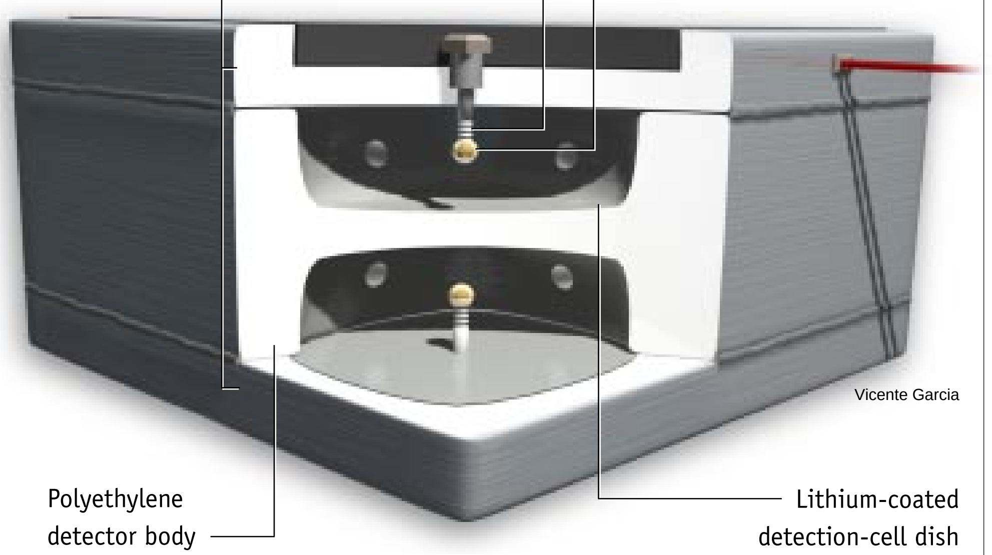
Government agencies are currently fielding neutron detectors at seaports, airports, rail yards, and border crossings to detect contraband plutonium from its neutron emissions. The aim is to foil terrorist attempts to smuggle a plutonium-fueled nuclear bomb or its plutonium parts into the country. Detonating a nuclear bomb in a city would be devastating.

But preventing such an attack is not easy because there are so many entry points to the United States. Each year, 7 million freight containers are unloaded at nearly 400 seaports; 800,000 commercial airline flights and 130,000 private flights land on U.S. soil; and 11 million trucks and 2 million railroad cars enter the country from Canada and Mexico. At each of the fifty or more vehicular border crossings, there are at least ten traffic lanes. To cover all these entry points would require several thousand neutron detectors, possibly tens of thousands.

The most commonly deployed neutron detector—a proportional counter—costs at least $30,000 for a model with a detection area of 1 square meter. Ten thousand of these detectors would cost at least $300 million.

Los Alamos scientist Kiril Ianakiev has developed an attractive alternative: a new breed of neutron detector. The detector's major parts include spark plugs, welding gas, and a briefcase-sized block of plastic that forms its body. The detector is rugged and inexpensive enough to be widely deployed—which is the whole idea.

Ianakiev's detector is also a good neutron detector: it detects 10 percent of the neutrons emitted by plutonium-240 that strike it. (Weapons-grade plutonium



A computer rendering of two argon-filled detection cells in an eight-cell detector. The high-energy neutrons emitted by plutonium are moderated to lower energies by the detector's polyethylene body so that they can be more readily absorbed by a cell's lithium coating. Nuclear reactions in the lithium produce tritons and alpha particles, about half of which penetrate the coating and ionize the cell's argon gas, producing electrons and positively charged ions. A radial electric field draws electrons to the spherical positive electrode and ions to the cell's negatively biased metal surfaces. The electron flow produces a current pulse, which is the detection signal.

typically contains about 5 percent plutonium-240.) By comparison, a proportional counter detects 15 percent of the neutrons. But a proportional counter is also nearly ten times more expensive. One of Ianakiev's detectors with a 1-square-meter detection area will cost about $4,000. Ten thousand detectors would cost only $40 million.

Leveraging the Microchip

To achieve this performance-to-cost breakthrough, Ianakiev has used modern electronics to redesign an old radiation detector. In 1908, scientists discovered that an energetic charged particle, an x-ray, or a gamma ray will produce a current pulse in gas that is subjected to an electric field. The radiation strips electrons from the gas atoms (ionizes them), and the electric field draws the resulting electrons and ions to the detector's positive and negative electrodes, respectively. The flow of electrons produces a tiny current pulse—the detection signal.

If the electric field is high enough, however, the electrons gain enough energy to ionize more gas atoms, a process that produces more electrons. The resulting "avalanche" of electron-ion pairs—called gas multiplication—amplifies the current pulse.

In the early days of radiation detectors, it was far easier to amplify the current pulses with gas multiplication than it was to amplify them with vacuum tubes, which had just been invented in 1906. Now, however, an inexpensive microchip can amplify the current pulses without gas multiplication, allowing Ianakiev to develop a detector that overcomes the limitations of early detector designs. (The sidebar on page 19 explains how gas-filled radiation detectors work.)

Detecting Neutrons

A gas-filled radiation detector cannot detect neutrons directly, however, because a neutron cannot ionize an atom. But several neutron-absorbing nuclear reactions produce energetic charged particles that do ionize atoms. These reactions include

neutron + ^{6}Li → triton + alpha particle,
neutron + ^{3}He → triton + proton, and
neutron + ^{10}B → ^{7}Li + alpha particle,

where Li is lithium, He is helium, B is boron, and the superscripts are isotopic numbers. A triton is the nucleus of a tritium atom (hydrogen-3); an alpha particle is the nucleus of a helium atom.

The reaction rates are significant only for neutrons with kinetic energies close to the thermal energy of their surroundings, about 0.025 electronvolt at room temperature. For the 1-million-electronvolt neutrons emitted by plutonium-240, the reaction rates are about one-thousandth those of thermal neutrons. To be detected, therefore, the plutonium neutrons must first lose energy in many glancing blows with a succession of nuclei, a process called moderation. Because light nuclei such as those from hydrogen atoms efficiently moderate neutrons, neutron detectors usually include a block or sheet of a hydrogenous moderator, such as paraffin or polyethylene.

Tough, Smart, and Modular

In Ianakiev's design, the detector's body is the moderator. The body of his current prototype is an 18×18×13-centimeter (7×7×5-inch) block of high-density polyethylene—a strong, durable plastic. The block contains a single rectangular detection cell filled with argon at atmospheric pressure. About 60 percent of the block is solid polyethylene. In addition to enhancing the detection efficiency, the mass of polyethylene makes the detector tough.

Embedded in the detector's body are electronic modules that condition and analyze the detection signal and monitor detector performance. An onboard microprocessor makes the detector easy for untrained operators to use and permits detectors to be networked.

The bottom of the detection cell looks like an oversized metal soap dish (see the drawing on page 20). Deposited on the cell's inner surface is a thin layer of lithium-6, which absorbs moderated neutrons and produces alpha particles and tritons. The layer is thick enough for a high reaction rate yet thin enough for about half of the tritons and alpha particles to penetrate the layer and

Gas-Filled Radiation Detectors

A gas-filled radiation detector is usually a glass tube that contains two concentric electrodes and a gas such as argon. The outer electrode is a metal tube; the inner electrode is a wire stretched between the ends of the tube along its axis. Energetic charged particles, x-rays, or gamma rays entering the detector strip electrons from the gas atoms to produce positively charged ions and negatively charged electrons. An electric field created by several hundred volts or more across the electrodes draws the ions to the negative electrode and the electrons to the positive electrode. The electron flow produces a current pulse, which is the detection signal. The charge produced by a 1-million-electronvolt charged particle coming to rest in the gas is about 5 femtocoulombs.

The magnitude of the electric field determines the detector's mode of operation. In order of increasing electric field, the detector operates as an ionization chamber, a proportional counter, or a Geiger-Müller tube. The modular neutron detector operates as an ionization chamber.

The field in an ionization chamber is high enough to prevent the electron-ion pairs produced by the radiation from recombining but too low for the electrons to produce additional electron-ion pairs in collisions with gas atoms. Because the current pulse produced by each radiation packet is proportional to the energy the packet ultimately deposits in the detection gas, the detector can measure the distribution of the deposited energies. This feature allows a neutron detector to discriminate between neutrons and background gamma rays, as shown in the figure on page 21. (Most of the background radiation comes from gamma-ray-emitting radioactive isotopes in the environment, such as potassium-40, uranium-238, and thorium.) However, the current pulse is so weak that it must be amplified electronically.

In a proportional counter, the field is high enough for the electrons to produce additional electron-ion pairs—an amplifying process called gas multiplication. A proportional counter requires only minimal electrical amplification. However, the field is still small enough to preserve the proportionality between the current pulse's amplitude and the energy deposited by the radiation packet. Thus, a proportional counter can also discriminate between neutrons and background gamma rays. The amplification factor of a proportional counter increases as the field increases.

At an even higher field, however, a gas-filled detector's proportionality is destroyed, and the amplitude of the detection signal is constant no matter what the deposited energy. A radiation detector operating in this mode is a Geiger-Müller tube, which needs little or no electrical amplification but cannot be used to measure the deposited energies. This tube is the heart of the Geiger counter.

Vicente Garcia

A computer rendering of a fieldable modular neutron detector, which will have eight detection cells and a detection area of 0.21 square meter. Most of the detector is high-density polyethylene. Electronics embedded in the detector's body amplify the detection signal, provide high voltage for the detection cells, and enable the detector to communicate with other detectors. Stacked on their sides, modular detectors could be used to build neutron-detection walls along highways, inspection arches at vehicle entry points, and distributed-detector networks encircling facilities or towns.

ionize the cell's gas. The optimal thickness for the layer was calculated by Los Alamos scientist Martyn Swinhoe.

Because lithium will not bond directly to polyethylene, the lithium is deposited on a metal substrate that does bond to the plastic. The substrate also prevents the gases emitted by polyethylene from entering the detection volume.

A flat polyethylene lid with a lithium undercoat covers the top of the cell and provides a flat surface for an O-ring gas seal. The lid is bolted to the detector's body. Filling the cell with argon at atmospheric pressure simplifies adding the gas during detector manufacture and eliminates the safety problems of pressurized vessels.

With the lid in place, the detection volume is completely enclosed by metal, which improves detection sensitivity by shielding the volume from the electrical noise produced by power lines and other external sources. The metal enclosure is also the detector's negative electrode. A thin aluminum sheet on the detector's exterior electrically shields the embedded electronic modules.

The cell's positive electrode is a metal ball screwed onto the end of a modified spark plug, which extends from the lid into the detection cell. In addition to providing an insulated connection to the positive electrode, the spark plug—built to withstand the harsh, percussive environment of an internal combustion engine—will not vibrate if the detector is bumped.

The shortest dimension of the detection cell—its depth—equals the longest distance a lithium-produced triton will travel in argon at atmospheric pressure before coming to rest. Because a lithium-produced alpha particle will travel an even shorter distance, both the tritons and the alpha particles ionize as much argon as possible, providing maximum detection sensitivity.

Head-to-Head with the Proportional Counter

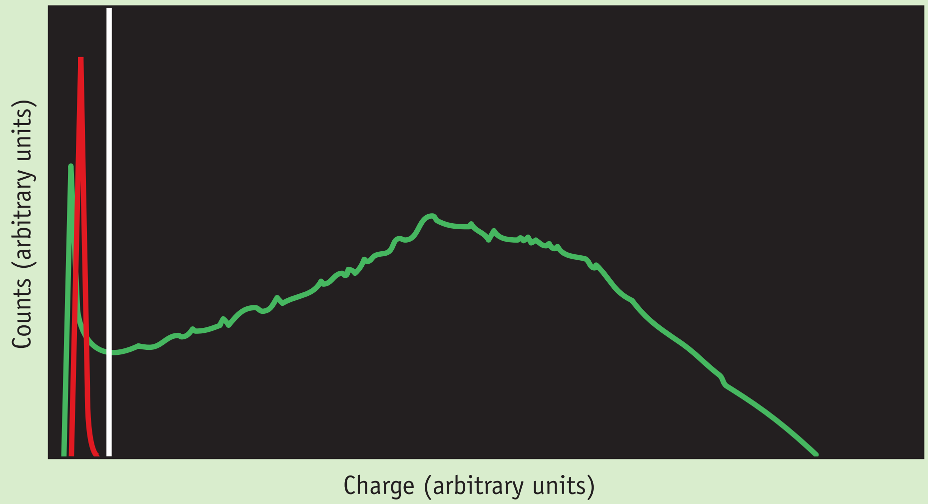
The neutron detectors now being deployed are proportional counters filled with either helium-3 or gas compounds made with boron-10. Proportional counters have been the workhorses of neutron detection for decades. A proportional counter with a detection area of 1 square meter requires about twenty 1-meter-long gas-filled tubes, each costing about $1,200.

Because a proportional counter uses gas multiplication, its detection signal is highly sensitive to gas impurities. Thus, the gas in a proportional-counter tube must be at least 99.999 percent pure. In fact, about half the cost of a helium-3 proportional-counter tube is in its high-purity gas. In contrast, Ianakiev's detector—which does not use gas multiplication—works even with inexpensive welding-grade argon, which has a purity of 99.5 percent. Furthermore, the small amounts of oxygen, water vapor, and carbon dioxide slowly emitted from the detector's interior surfaces will be absorbed by the lithium coating, so that outgassing will not affect detector performance for twenty years or more.

Finally, because the proportional counter's wire electrode can easily be made to vibrate—and thereby to produce spurious signals—the detectors are susceptible to shock and vibration. Supported by a robust spark plug, the relatively massive spherical electrode in Ianakiev's detector resists vibration.

Fieldable Detectors

Ianakiev's detector is rugged, reliable, and versatile—in addition to being a good neutron detector. To reduce the cost of his fieldable detectors, Ianakiev plans to use mass-production techniques and inexpensive materials. For example, he will form the detector's body from high-density polyethylene with injection molding, a common technique for making inexpensive plastic parts. He will use electroplating or sputtering techniques to lay down the detection cell's metal substrate. Finally, he will deposit the lithium layer over the substrate with techniques used to mass-produce lithium batteries. Such techniques should make it practical and economical to deploy neutron detectors wherever they are needed to counter terrorist nuclear threats. ■



Measurements made with a single-cell prototype of the modular neutron detector. Two isotopes were used for the tests: cesium-137 (red), which emits gamma rays, and californium-252 (green), which emits alpha particles, neutrons, and gamma rays. The horizontal axis is the charge produced in the detection cell by the radiation packets, which include gamma rays and the tritons and alpha particles emitted from neutron-absorbing reactions in the cell's lithium layer. (Californium-252's alpha particles are absorbed by the source's container before they reach the detector.) The vertical axis is the number of radiation packets that produce a given value of charge. The two sharp peaks on the left are produced by the sources' gamma rays. The remaining data is from neutrons. When the detection threshold is set at the white line, the detector responds only to neutron-emitting materials such as plutonium and rejects gamma-ray-emitting materials such as radioactive pharmaceuticals or radioactive elements in the environment. By discriminating between these two types of radioactive materials, the detector yields fewer false positives, increasing inspection efficiency.

The Researchers

Kiril Ianakiev has an M.S. in electrical engineering from the Technical University of Sofia, Bulgaria. Before joining Los Alamos as a technical staff member in 1996, he consulted at Los Alamos and for the International Atomic Energy Agency in Vienna on low-power, pulse-height analysis technology. He has six patents for nuclear instruments.

Martyn Swinhoe has a Ph.D. in nuclear physics from the University of Birmingham, United Kingdom. Before joining Los Alamos as a technical staff member in 2002, he worked at the Harwell Laboratory in the United Kingdom and as a Euratom safeguards inspector in Luxembourg.

John Flower

Spotlight
Los Alamos in the News

Yixiang Duan adjusts a filter in his portable air-particulate monitor; the front panel has been removed to show the monitor's microwave-plasma torch, a key to its capabilities.

Leonardo Civale, Fred Mueller, and Adriana Serquis of the MST team.

Technology Maturation Funds Awarded

In June, the Industrial Business Development Division awarded funds to Yixiang Duan of the Chemistry Division and to a team from the Materials Science and Technology (MST) Division to help develop the licensing potential of their technologies. The awards came from the Technology Maturation Fund, an internal source of "venture capital" created to promote Lab technologies that have strong commercial potential. Award criteria include a compelling market need and strong likelihood of commercialization for the technology and a commitment to technology transfer on the part of the principal investigators.

Duan will use his award to test a prototype of his portable, real-time air-particulate monitor that can detect sixteen hazardous elements, including beryllium and heavy metals such as vanadium, cadmium, lead, and cobalt. His technology can be used in the mining and manufacturing industries to continuously monitor the workplace for airborne hazards. Duan is developing the prototype to demonstrate the monitor's capability to prospective licensees.

The MST team of Adriana Serquis, Leonardo Civale, Yuntian Zhu, Fred Mueller, and Duncan Hammon will use its award to produce and test prototype coils of magnesium diboride superconducting wire. The wire shows promise for reducing the size and cost of magnetic resonance imaging machines and power transformers. The funding will enable the team to demonstrate the wire's performance and cost-effectiveness to prospective licensees.

Since December 2002, the Industrial Business Development Division has reviewed twenty-two proposals from nine technical divisions for awards from the Technology Maturation Fund. To date, $250,000 has been disbursed in awards ranging from $10,000 to $50,000. Funded with royalty income from Laboratory licenses and money set aside for technology commercialization in the University of California contract, the fund is an ongoing effort to promote the transfer of Lab technologies to the private sector. Funding proposals are evaluated monthly by a panel of commercialization and licensing experts within IBD.

The first Technology Maturation Fund awards, made last February, appear to be moving several Laboratory technologies toward commercialization. A license was recently negotiated with ElectroChromix Inc. to commercialize electrochromic (autodarkening) mirrors and windows. A new cooperative research and development agreement is being developed with Motorola to integrate Lab image-analysis software into an advanced navigation system for vehicles. The Lab is also pursuing licensing inquiries about use of a micro-x-ray fluorescence technique for drug discovery and about technology that reduces nitrates in effluent water.—Marjorie Mascheroni

Lab Physicist Wins Russian Science Award

In May, Tom Bowles received the top scientific prize awarded by the Russian Academy of Sciences' Institute for Nuclear Research. He was awarded the M. A. Markov Prize for his work as a principal investigator of the Soviet-American Gallium Experiment (SAGE), a major solar-neutrino investigation. He shared the prize with Vladimir Gavrin and Vadim Kuzmin, both of the institute.

The annual award is named for the institute's founder, Moisey A. Markov, and recognizes substantial contributions to fundamental physics and the development of major research directions for the institute. Since 1986, Bowles, who works in the Laboratory's Physics Division, has led the American effort in SAGE, the first experiment to directly detect low-energy neutrinos from proton-proton fusion in the sun. These neutrinos, which are made in the primary reaction that provides the sun's energy, are the major component of the solar-neutrino flux.

Buried deep beneath the Caucasus Mountains at the Baksan Neutrino Observatory, SAGE counts solar-neutrino reactions inside tanks that contain 50 metric tons of gallium. Results reported by the SAGE team in the early 1990s, when it observed a few solar-neutrino signatures every month, electrified the scientific world. The neutrino capture rate was well below that predicted by the Standard Solar Model, a discovery that suggested the solution to the solar neutrino problem lay in the neutrino itself. The significant suppression of the solar-neutrino flux that SAGE and other solar-neutrino experiments have observed gives strong credence to the existence of neutrino oscillations.

"This is a great honor and shows the importance the Russian science community places on this groundbreaking, 17-year partnership," Bowles said. "SAGE is often cited as one of the very best examples of Russian-American scientific collaborations."—Jim Danneskiold